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STUDIES

PAPERS FROM THE PHYSICAL  
LABORATORIES

No. 76: ON THE ELECTRICAL CONDUCTIVITY OF COPPER  
FUSED WITH MICA, BY A. L. WILLIAMS

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*On the Electrical Conductivity of Copper fused with Mica.*  
By Sub-Lieut. A. L. WILLIAMS, R.N., with Introduction  
by Prof. J. C. McLENNAN, F.R.S.\*

[Plates V.-VII.]

INTRODUCTION.

WHILE acting as Scientific Adviser to the Admiralty, I had my attention drawn by Sub-Lieut. A. L. Williams, R.N., to some experiments made by him in the early part of 1919 at Cambridge, in which he found that samples of copper when fused with mica exhibited a remarkably large fall in resistance when gradually subjected to rising temperatures.

During a short furlough he was given an opportunity at the Admiralty Physical Laboratory, South Kensington, to develop this discovery and, on going back to duty, he left with me some notes embodying the results of his work. I have not had an opportunity of communicating with him again, but as the results are interesting it is thought they should be duly recorded. His experiments are described below, and accompanying them are some additional notes of results obtained at the University of Toronto by Miss Isabel Mackey and Miss I. Giles, who have followed up the subject still further.

J. C. McLE.

A.

EXPERIMENTS BY SUB-LIEUT. A. L. WILLIAMS, R.N.

I. *Preparation.*

The samples for test were all prepared in the open on a piece of iron or copper plate—used as an anode—and a carbon rod as the cathode, the arc being struck at first between the plate and carbon, and then, when hot, to the mixture. The mica was first melted, then the copper added. In making up the samples studied, about equal proportions of copper and mica were used.

II. *Effect of Temperature.*

Resistance temperature measurements for two samples were made for a range of temperatures from 27° to 850° C. For sample A, the curves of which are attached, Graphs 1 and 2 (Pl. V.), the resistance fell from 16,000 ohms at 27° C., to 0.5 ohm at 850° C.

\* Communicated by Prof. J. C. McLennan.

## III. Notes.

(1) It was noted that the material was malleable at 2000° C.

(2) A specimen piece was rolled at this temperature a small rod 2.5 mm. in diameter for the purpose of determining the specific resistance of the mixture. It was found to be as follows:—

25° C., Specific Resistance, 10,400 ohms

30° C.,       "       "       "       8,000 ohms

(3) An attempt was made to obtain a sample of the mixture in the form of a very thin film for delicate measurements, etc., and it was found possible to draw out to about 1/1000 of an inch between platinum foil. It was not possible, however, to separate the film from the foil. The two pieces of foil cemented together by this fine film. The mixture was found to be extremely sensitive to heat. The resistance responded to the action of infra-red rays from an electric lamp one yard away, notwithstanding the comparatively large volume of platinum to be heated first.

It is thought that with suitable films of the mixture enclosed in hydrogen it may be possible to use them for signalling purposes. It is also suggested that films may be used instead of wires in microphones for transmitting, as the changes of resistance, due to change of temperature, are quite considerable, being some thousands of ohms per degree centigrade with some samples.

(4) Attempts were made to make thin sheets of the copper-nica material, finely powdered, with fine particles in the form of cane-sugar, and driving off the water by heating. The resistance of the resulting material was extremely high, but very regular thin sheets were obtained in this way. It is possible, when the resistance of this mixture is increased by compression in an electric press, that it may be obtained in sheets, rods, or other forms, having a moderate resistance and yet possessing a high resistance-temperature coefficient.

(5) Attempts to cast the material in various forms were unsuccessful, partly owing to the difficulty in working at the requisite high temperatures. The material, when absorbed by such porous substances as porcelain, or glazed porcelain is used the glazing melts and mixes with the material. It is possible that castings could be obtained using fused quartz as a moulding material.

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6. Attempts were made to make up similar compounds with the following metals and mica:—

*Tin.* The metal vaporized at too low a temperature.

*Silver.* Did not combine.

*Platinum.* Did not combine.

*Iron.* Combined, but no resistance temperature measurements were made.

## B.

### EXPERIMENTS BY MISS MACKAY.

#### I. Experimental Arrangements.

(a) The samples to be tested were all made in the open on a piece of iron plate used as an anode and a carbon rod as a cathode. The current was controlled by a large rheostat giving up to 30 amperes on the 110 d.c. circuit. An arc was struck between the plate and carbon and, when hot, the mica was melted and the other material added.

(b) A quartz tube closed at one end and covered with nichrome wire was used as a receptacle in which to melt the material and form it into a regular cylindrical shape for experimental work.

(c) A small electrical furnace was used to heat the material. It consisted of a circular porcelain foundation covered with wire and all was covered with asbestos except the two binding posts.

#### II. Results.

(a) *Mica and Copper.*—Mica and copper were fused on the iron plate into small lumps, and some of these were then finely ground into powder. No traces of mica or copper could be detected, only a uniform dull black powder. The powder was put into a quartz tube and heated, but this did not prove a satisfactory method of obtaining the mixture in the form of solid rods, as part of the mixture fused in the quartz, and it was found impossible to separate the two substances. When the quartz was broken, the copper-mica was found to be very brittle and not at all suitable for resistance measurements. Platinum wires were then fused into the ends of the copper-mica lumps which had not been powdered, and the variations in the resistances of these lumps were observed when they were raised to various temperatures.

Two different samples of copper and mica were placed in the furnace for variation in resistance with temperature only up to about 400° C.). In Case No. 1 (Graph No. 3) the resistance was found to vary from 4100 ohms to 300 ohms while the temperature varied from 25° C. to 400° C. The specific gravity of the specimen was found to be 5.7, while the specific gravity of copper is given by 8.9, it will be seen that the specimen contained considerable mica.

GRAPH NO. 3.

Temperature, ° C.	Resistance (Ohms).	Temperature, ° C.	Resistance (Ohms).
22	4,400	148	1,200
46	3,600	154	1,100
54	3,200	164	1,100
58.5	2,940	206	700
61	2,900	260	600
65.5	2,800	275	400
70	2,460	315	400
72	2,400	344	300
93	1,950	364	200
127	1,550		

In Case No. 2 (Graph No. 4) the variation in resistance was from 95,000 ohms to 3000 ohms, while the temperature changed from 100° C. to 400° C. The specific gravity was found to be 4.3.

GRAPH NO. 4.

Temperature, ° C.	Resistance (Ohms).	Temperature, ° C.	Resistance (Ohms).
139	45,550	228	11,300
178	23,330	241	13,500
236	11,645	208	14,500
262	9,120	200	16,700
314	6,000	192	19,000
345	4,590	172	23,400
364	3,790	165	26,200
378	3,605	155	29,600
395	3,280	147	34,000
393	4,200	139	40,500
323	4,740	130	44,300
313	5,490	122	51,300
290	6,320	118	57,100
278	7,030	113	64,000
267	7,790	108	74,000
256	8,610	103	81,700
245	9,410	99	91,000
232	10,790		

From these results it would appear that an increase in mica-content of the mixture raises the resistance at



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Temperature, °C.	Resistance (Ohms).
1,250	
1,150	
1,100	
780	
611	
450	
400	
340	
281	

variation in resistance  
while the temperature  
specific gravity was

Temperature, °C.	Resistance (Ohms).
11,370	
13,585	
14,570	
16,738	
19,090	
23,445	
26,230	
29,670	
34,050	
40,505	
44,350	
51,340	
57,110	
64,070	
74,033	
81,740	
91,010	

at an increase in the  
resistance at ordinary

temperature and causes the fall in resistance with temperature to be much more rapid.

While more brittle than copper, the copper-mica is not as brittle as iron-mica compounds described below. The hardness is almost the same as that of glass. X-ray photographs showed the composition to be quite homogeneous. The mixture was black with a dull metallic lustre.

(b) *Iron and Mica*.—Two mixtures were made as in the case of the copper and mica, and the temperatures and resistances were measured as before. In Case No. 1 (Graph No. 5) the resistance fell from 1300 ohms to 100 ohms on being heated from 25° C. to nearly 300° C.

GRAPH No. 5.

Temperature, °C.	Resistance (Ohms).	Temperature, °C.	Resistance (Ohms).
26	1,350	303	91
42	980	308	90
47.5	890	165	235
52.5	825	138	310
54	790	116	380
101	410	97	490
131	350	75	650
138	340	83	590
178	219	64	765
195	180	55	860
209	160	51	905
218	150	45	1,010
165	280	40	1,070
214	170	38	1,110
263	115	33.5	1,203
282	103	31	1,240
294	95		

In Case No. 2 (Graph No. 6) the resistance fell from 32,000 ohms on being heated from 160° C. to 380° C.

GRAPH No. 6.

Temperature, °C.	Resistance (Ohms).	Temperature, °C.	Resistance (Ohms).
250	6,100	294	3,380
228	9,050	282	3,900
280	3,870	255	5,970
318	2,410	242	7,350
335	1,980	231	8,440
344	1,780	222	10,380
360	1,550	214	11,720
377	1,280	204	15,750
360	1,550	197	15,900
336	1,980	187	19,550
322	2,360	175	25,210
309	2,730	164	32,100

The hardness was above that of glass, and the material much more brittle than copper-mica and had more lustre. X-ray examinations showed the mixture to be homogeneous. The specific gravity in Case No. 1 and in Case No. 2 was 4. The specimens studied were irregular in shape, but from a rough examination of the samples, it appeared that the sample which had the higher mica-content was the one which had the higher specific resistance.

(c) *Aluminium and Mica*.—No fusion was observed between aluminium and mica. The two seemed to remain entirely separate.

(d) *Antimony and Mica*.—The antimony when heated off dense clouds of vapour, leaving nothing to fuse with the mica.

(e) *Bismuth and Mica*.—The same results were obtained as with antimony.

(f) *Cobalt and Mica*.—Cobalt and mica were fused on an iron plate in the same manner as the copper and mica. The cobalt-mica had a very dull black colour and was brittle, but hard enough to scratch glass. Platinum wires were fused in the ends with difficulty, and the resistance at ordinary temperatures was very great. When heated hot with a bunsen flame, a current of about 0.20 ampere was obtained, using the 110 circuit.

(g) *Nickel and Mica*.—When nickel and mica were fused the substance produced was very similar to cobalt-mica. When it was heated red hot, a current of about 0.00 ampere was obtained, using the 110 circuit.

(h) *Manganese and Mica*.—Mica and manganese do not seem to mix at all. In one test, the manganese was found to form a complete shell around the mica, and in other tests an X-ray photograph showed the two to be quite separate.

(i) *Silicon and Copper*.—It did not seem at all probable, indeed possible, to fuse copper and silicon. The two substances appeared to be quite separate after fusion.

(j) *Selenium and Copper*.—These fused quite readily and formed a dull black substance with very little or no lustre. The resistance was found at various temperatures and a graph, No. 8, drawn. The specific gravity was 6.4 and hardness less than that of glass. With this mixture it can be seen that a discontinuity occurred in the resistance measurements at about 150 C. The explanation of this result does not appear evident at present.



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# Conductivity of Copper fused with Mica.

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GRAPH No. 8.

Temperature, °C.	Resistance (Ohms).	Temperature, °C.	Resistance (Ohms).
370	.219	124	.261
335	.207	115	.200
315	.200	108	.176
298	.188	104	.172
260	.173	101	.169
247	.164	98	.169
240	.164	95	.168
230	.162	92	.163
221	.157	90	.164
204	.152	87	.164
190	.147	84	.163
180	.139	80	.165
173	.136	78	.167
167	.136	65	.176
160	.135	61	.176
154	.130	59	.177
136	.333	58	.176
130	.317	44	.185
127	.300		

(k) *Ferro-Silicon* —A sample of commercial ferro-silicon was also investigated. It was found to be very brittle and difficult to grind up into regular form for examination. In studying a sample, leading wires of iron were used, as platinum fused readily at the junction when the ferro-silicon was raised to a high temperature. When a graph was drawn between temperatures as abscissae and resistance as ordinates, the result was a straight line showing that the resistance varied directly as the temperature, just as in the case of ordinary pure metals. (See Graph No. 7.)

GRAPH No. 7.

Temperature, °C.	Resistance (Ohms relative).	Temperature, °C.	Resistance (Ohms relative).
280	.092	148	.078
259	.089	139	.077
246	.088	126	.076
226	.085	118	.075
214	.081	109	.074
202	.083	96	.073
185	.082	84	.071
176	.081	79	.070
165	.079	71	.070

C.

## EXPERIMENTS BY MISS GILES.

In these experiments a micrographic study was made of the plane polished surfaces of the fused copper-mica mixtures referred to above. These were made both when the mixtures

were at room temperatures and when their temperature gradually raised by means of an electric furnace. The object in view was to see whether the fused mixtures possessed a crystalline structure, and if they did whether the conductivity observed with them on raising their temperature could be connected in any way with observations on their crystal structure.

### I. Preparation of Specimens.

In preparing these specimens they were first ground off to an approximately flat surface. The surfaces were ground on a carborundum wheel, and after that on successive grades of aloxite of increasing fineness. The grades used were those commercially known as No. 220, and 3F respectively. The polishing was then done with optical alundum and finished with jeweller's rouge. The two coarsest grades of aloxite were used on a glass plate, while the finer grades and the optical alundum were used on fine even linen fabric stretched over a smooth plate. The rouge was used on a piece of soft, smooth cloth stretched over a glass plate. The plates were fastened on a horizontal revolving table rotated by an electric motor. In some cases the surfaces were etched in nitric acid of various concentrations ranging from 10 per cent. to 25 per cent. and even to 50 per cent. Better results, however, were obtained by the use of a 10 per cent. solution, with a specific gravity of about 0.93. In this solution the specimens were found to be uniformly etched by an attack of about one hour.

### II. Optical Equipment.

The microscope used was one of the instruments designed by Bausch and Lomb for micrographic work. For normal illumination the type of illuminator used was the usual reflecting disk of thin cover glass. In this type the light was projected at right angles to the top of the microscope, reflected from the cover glass into the optical axis of the system to the specimen, and then through the microscope. For visual examination of light was a frosted electric light bulb, while for micrographic work a small carbon arc was used. The plates used were rapid panchromatic, and the short wavelengths in the illuminating beam were cut out with a Wratten and Wainwright filter. Oblique, in place of normal illumination, was used in some cases.

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instruments especially rographic work. For minator used was the lass. In this method s to the optical axis of cover glass along the eimen, and then back xamination the source b, while for the photo- el. The photographic and the shorter wave- ent out with a Wratten ace of normal illumina-

### III. Results.

When examined under the microscope different specimens were found to exhibit different appearances. Most samples appeared to be quite uniform in structure, while in some many little globules could be seen, which from their lustre appeared to be pure copper.

Specimens which possessed a high temperature coefficient were found both under high and low power magnification to show no change in structure, either by normal or oblique illumination, when heated to temperatures as high as  $400^{\circ}\text{C}$ .

Pl. VII. fig. 1 shows the appearance of a specimen at room temperatures with a magnification of 46. The resistance of this sample, which was 3200 ohms at  $21^{\circ}\text{C}$ ., fell to 1600 when at  $95^{\circ}\text{C}$ . The structure of the specimen appeared very uniform, and no copper could be discerned in it judging by metallic lustre.

Pl. VII. fig. 2 shows the appearance of this specimen when etched with ammonia solution for an hour. As pure copper was found to require approximately about seven hours' exposure to ammonia to bring out its crystalline structure, the markings on the plate may be taken to indicate the boundaries between copper and mica or the constituents of the latter. The regularity of the markings would indicate that the copper and mica fused into an intimate and homogeneous mass.

A specimen, whose resistance at  $100^{\circ}\text{C}$ . was found to be 95,000 ohms and only 3000 ohms at  $400^{\circ}\text{C}$ ., was polished and examined previous to etching it with ammonia, both with high-power and low-power magnification, and with oblique and direct illumination.

Pl. VII. fig. 3 shows its appearance when illuminated obliquely under a magnification of 46.

Pl. VII. figs. 4 & 5 show the same region when illuminated by normally reflected light under magnifications 46 and 205 respectively. The structure in this case, as will be seen, is quite different from that shown in Pl. VII. fig. 1.

With the sample illustrated by figs. 3, 4, and 5 there appeared to be a great many streaks of light and dark, bounded by straight lines running in all directions, while in other specimens there appeared to be nothing uniform in the shapes of the patches. The portions of the surface which are dark in Pl. VII. fig. 3 it will be seen are light in Pl. VII. fig. 4. In this specimen much detail was brought out with the low-power objective. It was therefore used among others with low magnification to study the effect of any increase in temperatures. A water-cell provided with

running water was placed between the specimen and microscope objective, in order to cut off the heat from the objective, and the specimen was heated up to 400 C. No change could be discerned in the appearance of the surface.

Pl. VII, fig. 6 shows the appearance of a polished surface at a temperature of 350 C.

The specimen was then etched with the ammonium persulfate solution. Here, again, the surface was found to be marked by the etching after an attack of about an hour, but no copper was detected. It was heated again to 400 C. after etching, but no change in structure could be observed due to the high temperature.

#### IV. *Resistance-temperature coefficient of glass.*

In studying these specimens one gained the impression that they possessed a number of the characteristics of glass. In most cases the specimens were very hard, and they easily produce scratches on a glass plate with much less effort than copper. It is known, too, that many glasses when stroked with a piece of silk become electrically conducting, and with a view to making a comparison between the behaviour of these specimens and that of a sample of glass, some measurements were made of the resistance of a rod of glass when its temperature was gradually raised.

In these experiments a rod of "Schmelzglas" 8.0 cm. long and 5.0 mm. in diameter was used. Platinum wires were attached to the ends of the rod, and the circuit with the mains of the 110 volt D.C. circuit. When the glass portion was placed within an electric furnace, as the temperature rose observations were made on the resistance, which passed and on the fall of potential between the ends of the glass rod, contact being made with the ends by platinum junctions.

In these observations practically no current was able to pass through the glass until a temperature of about 350 C. was reached. Even then the current was only of the order of  $10^{-7}$  ampere, which showed that the resistance of the glass at this temperature was very high, practically absolute.

From this result it would appear that the high resistance-temperature coefficient possessed by the fused copper mixtures is something specific, and it does not appear to be a remarkable property they exhibit finds a direct parallel in the behaviour of glass.

The Physical Laboratory,  
University of Toronto,  
May 15th, 1920

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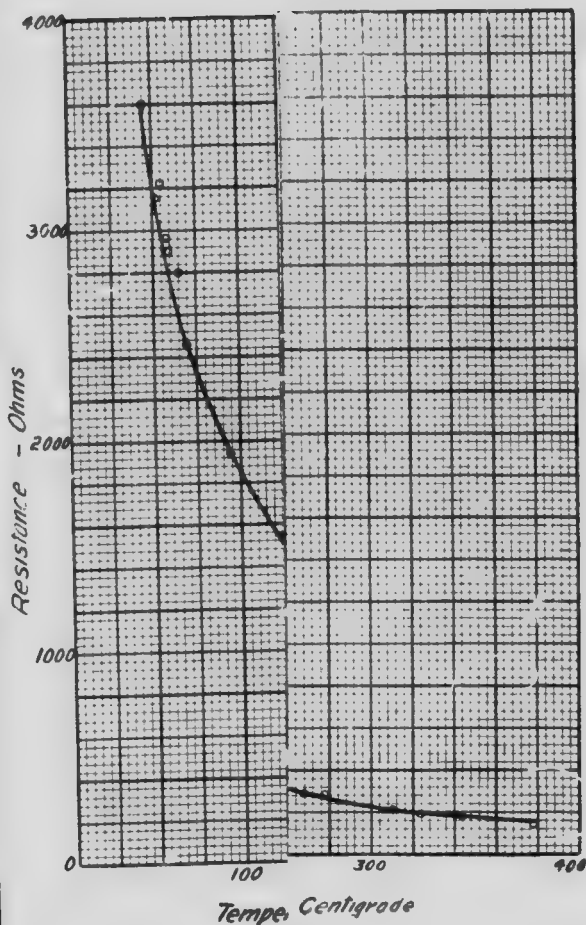
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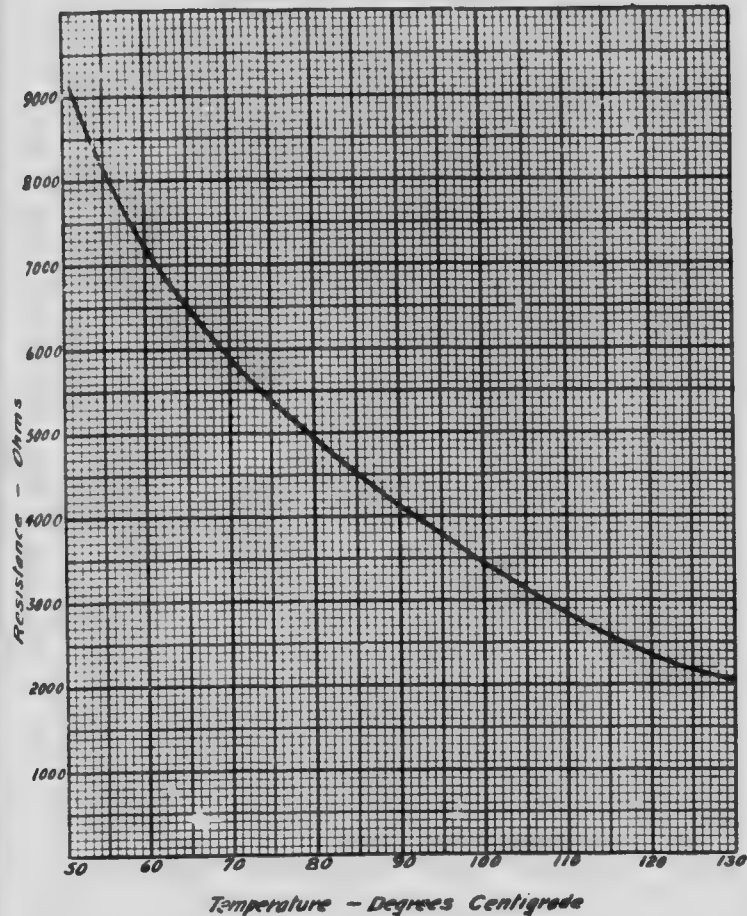
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Fig. 4  
FUSED MICA

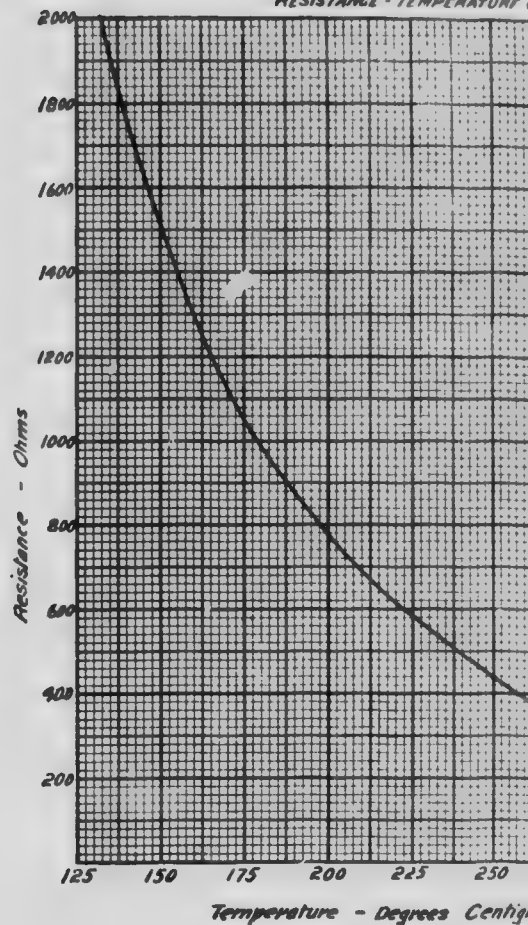


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Graph N°1  
COPPER - MICA  
RESISTANCE-TEMPERATURE CURVE

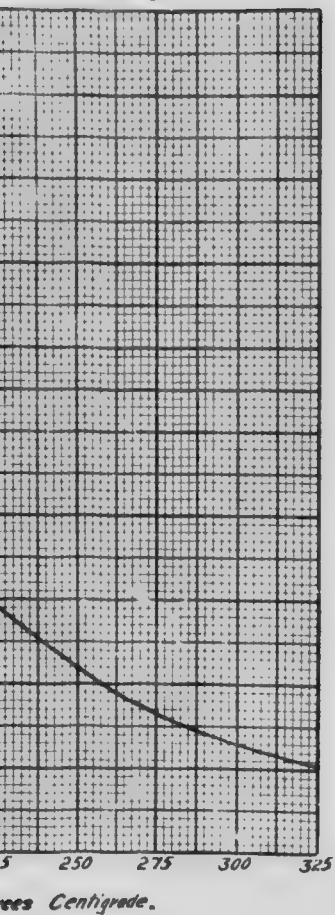


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COPPER - MICA  
RESISTANCE-TEMPERATURE CURVE

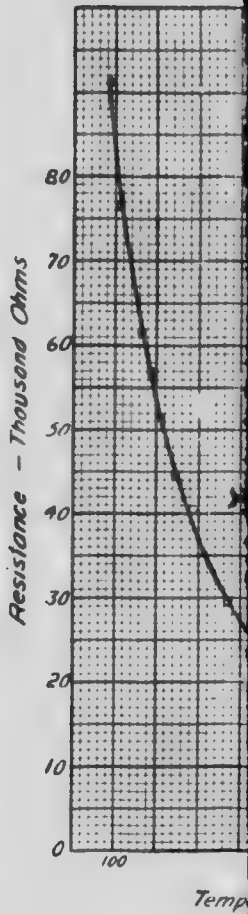
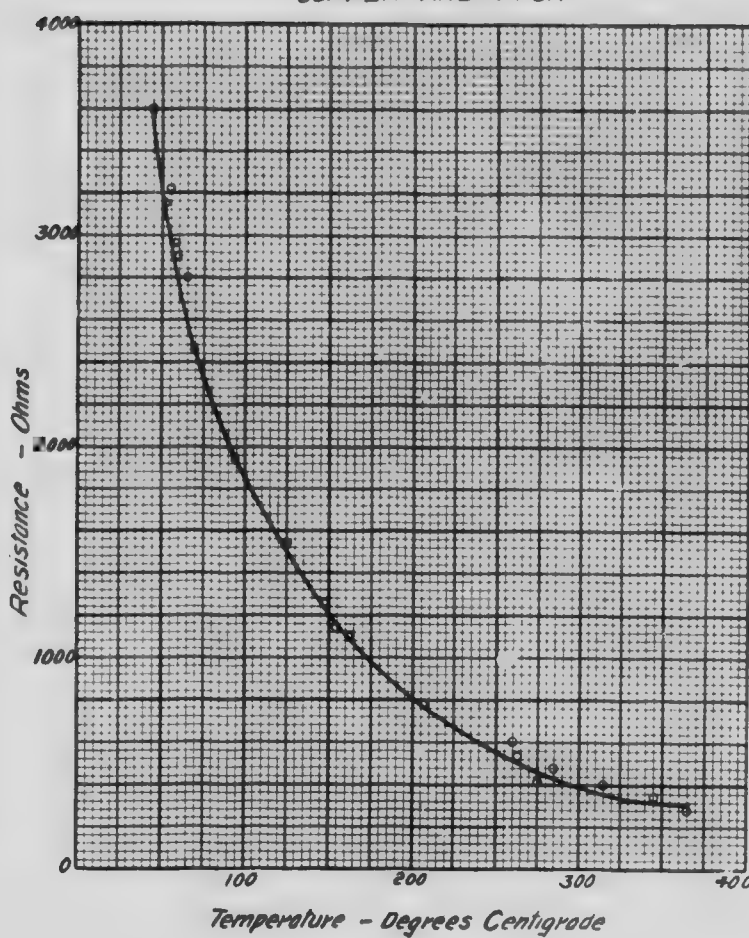




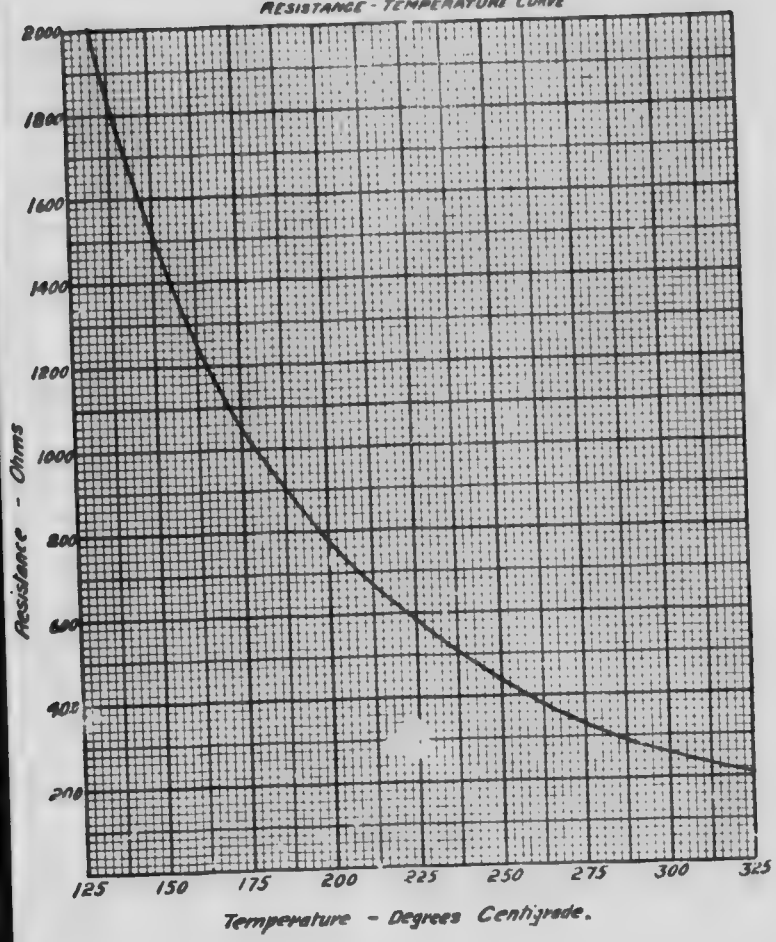
Nº 2  
- MICA  
TEMPERATURE CURVE



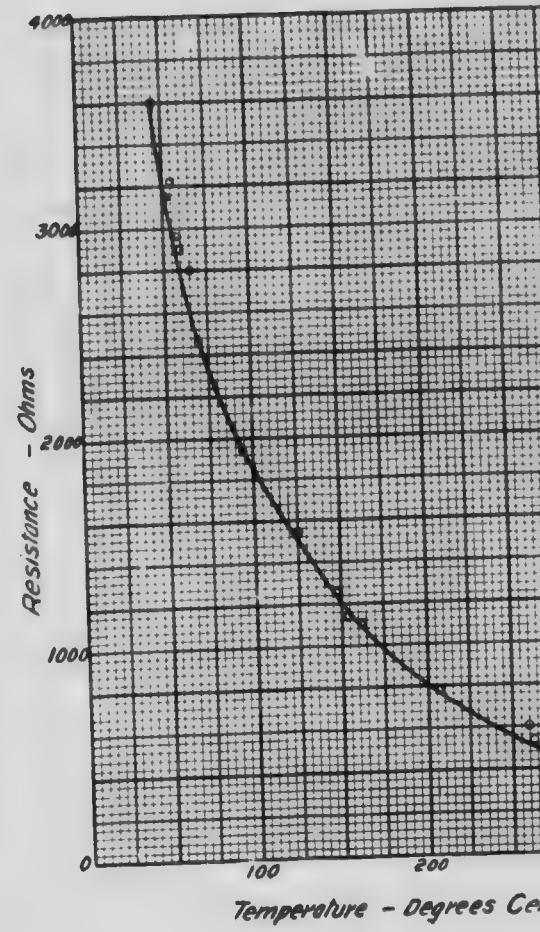
Graph N° 3  
COPPER AND MICA



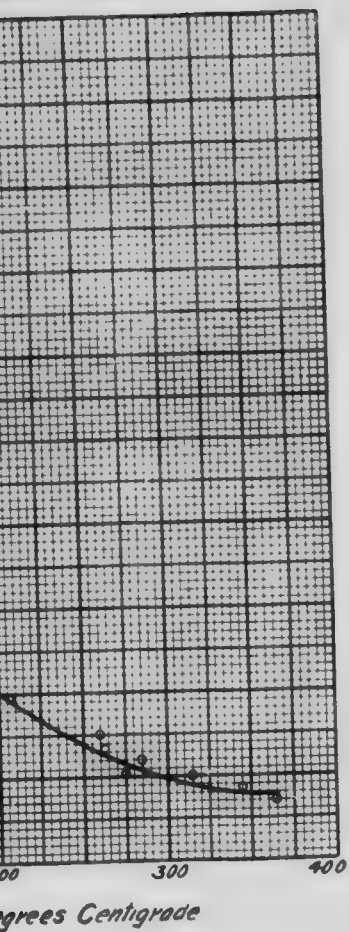
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COPPER - MICA  
RESISTANCE - TEMPERATURE CURVE



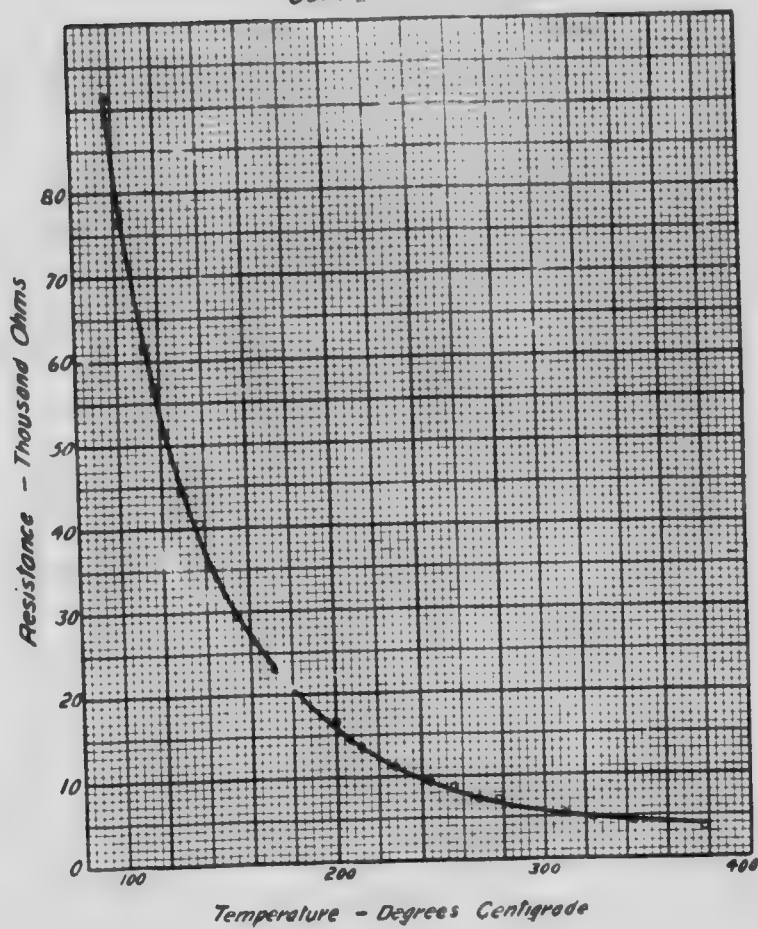
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COPPER AND MICA



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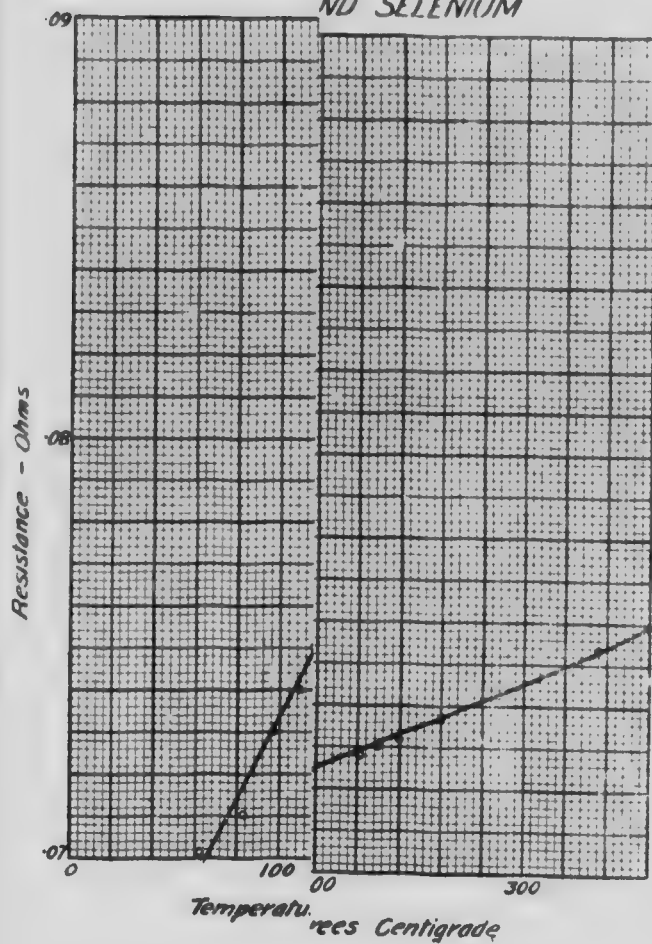
Graph N° 4  
COPPER AND MICA



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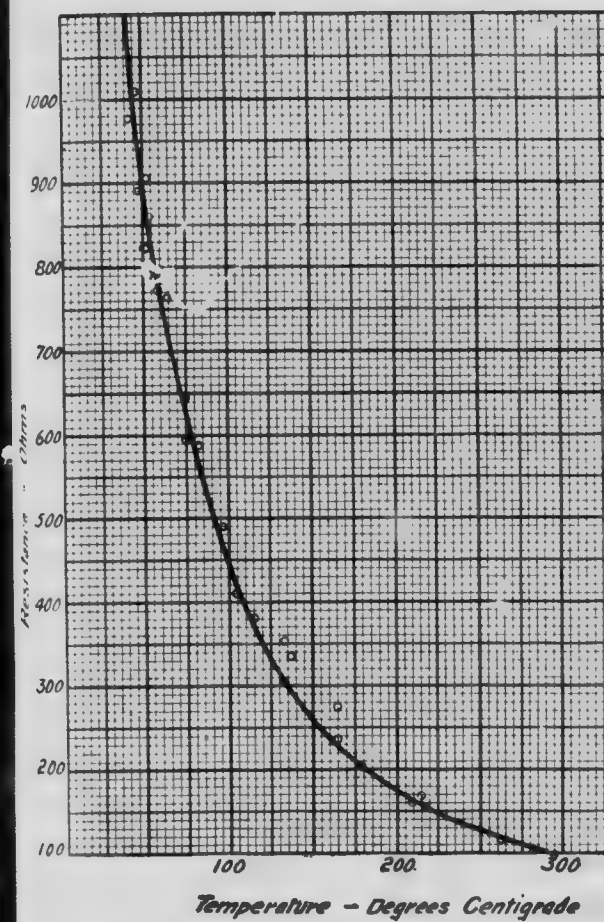
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Nº 8  
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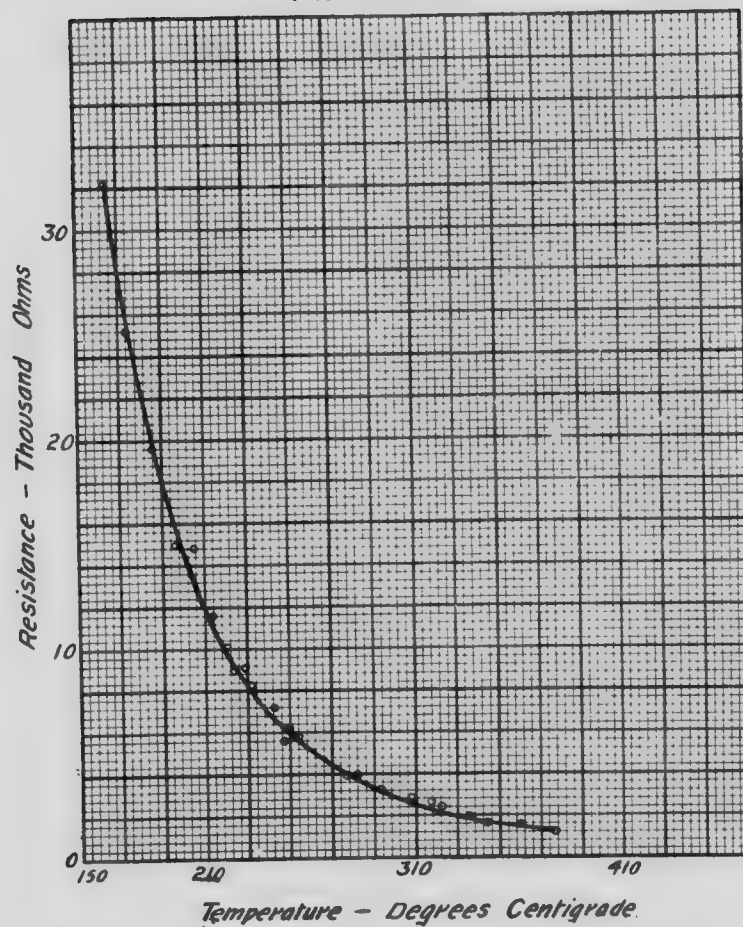
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Graph No 5  
IRON AND MICA

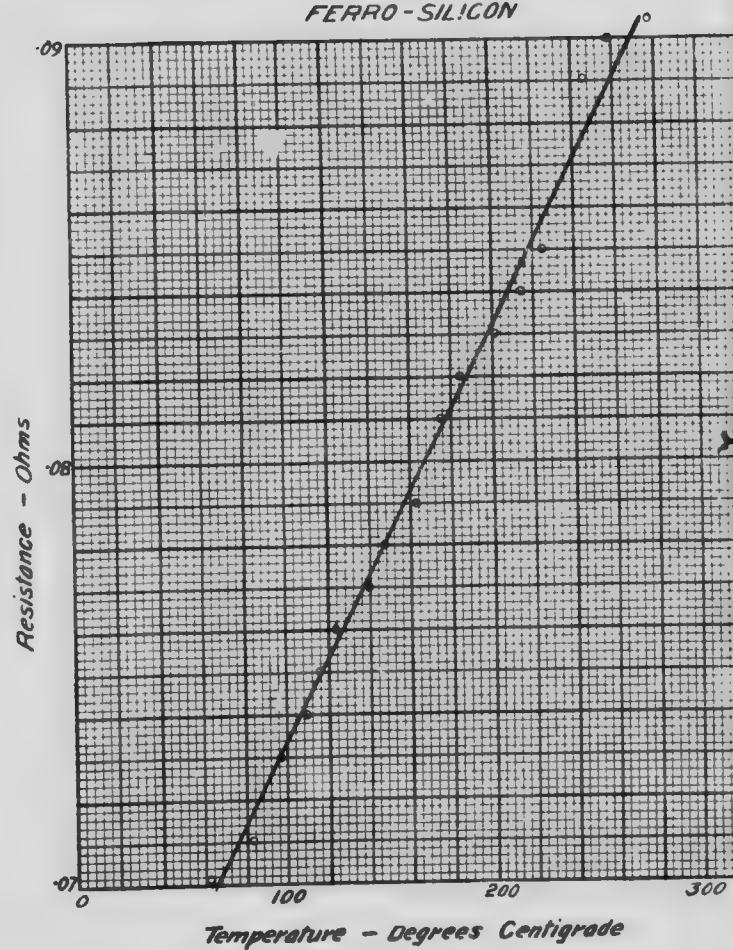




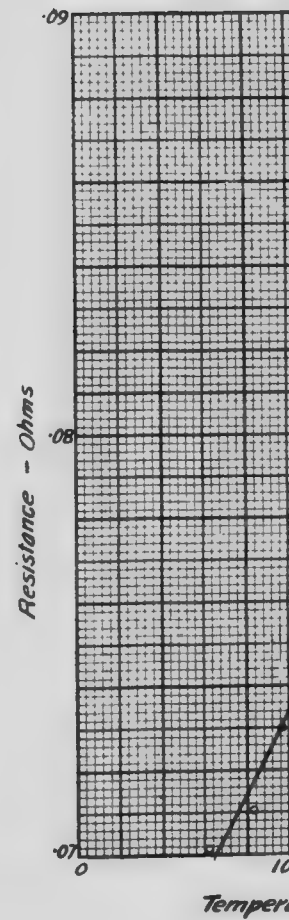
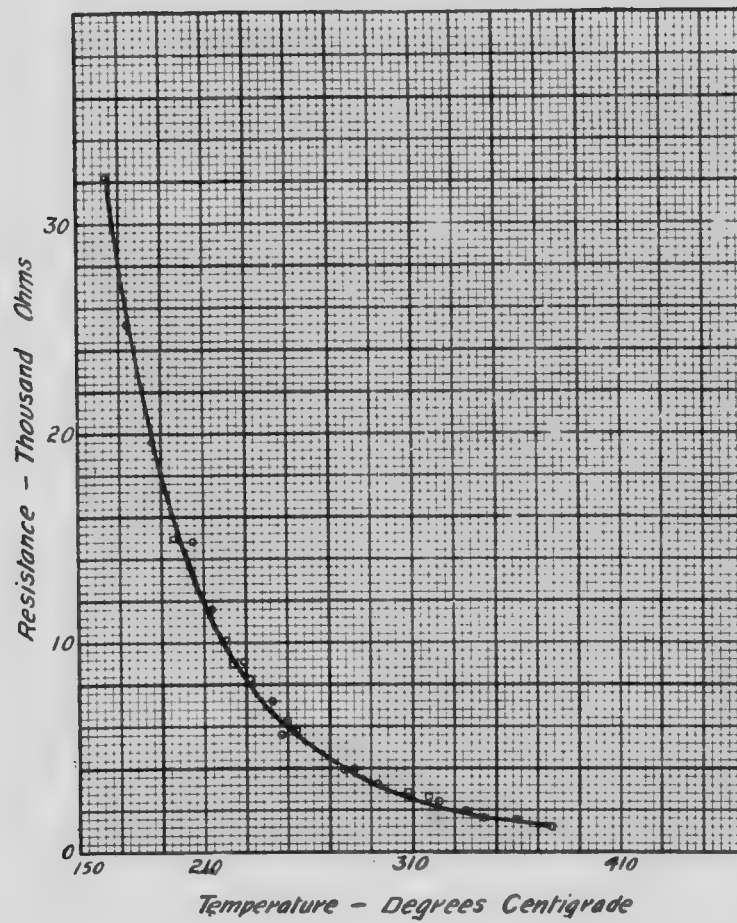
Graph N° 6  
IRON AND MICA



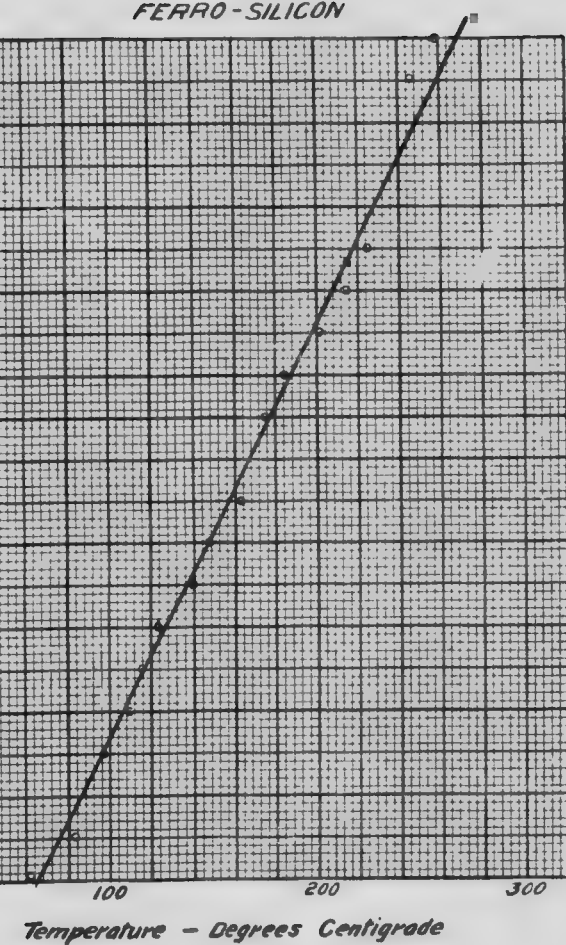
Graph N° 7  
FERRO-SILICON



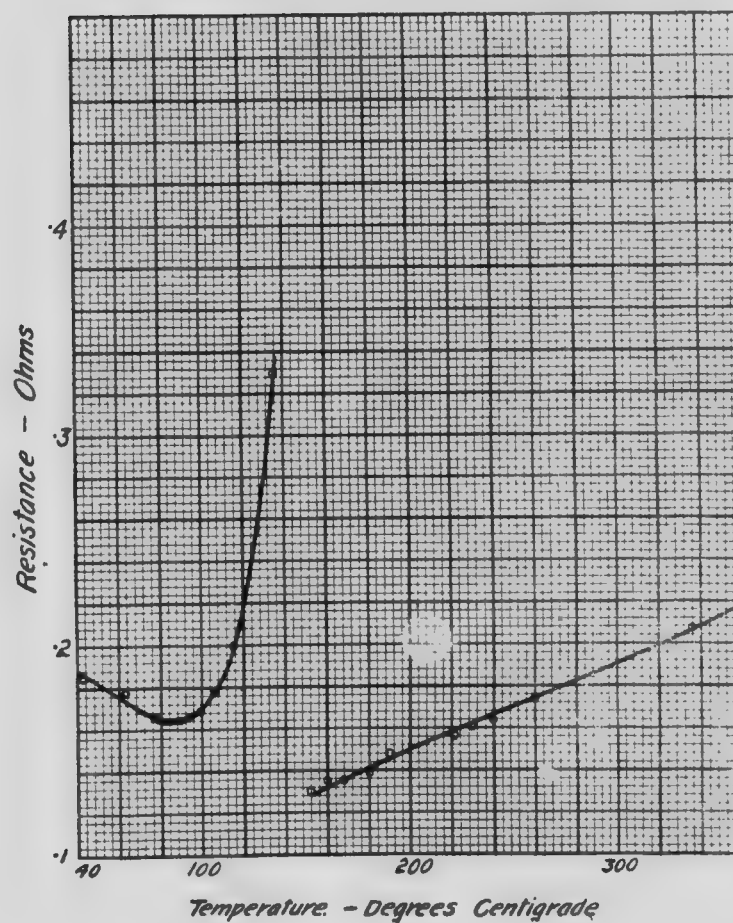
Graph N° 6  
IRON AND MICA



Graph N° 7  
FERRO-SILICON



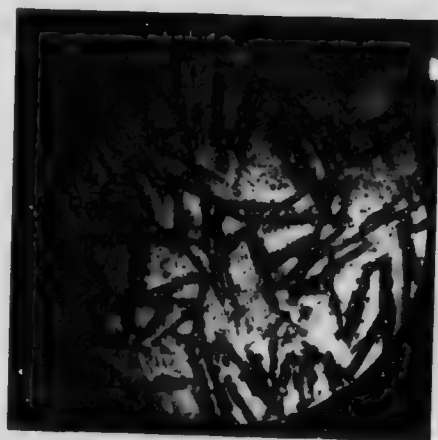
Graph N° 8  
COPPER AND SELENIUM





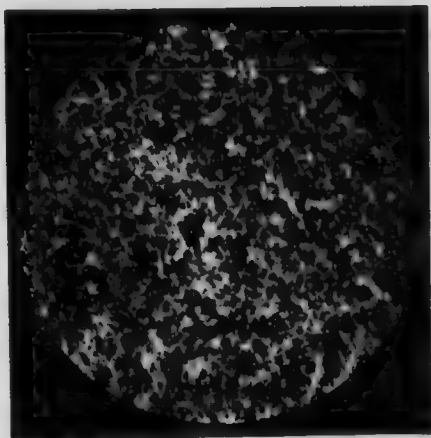


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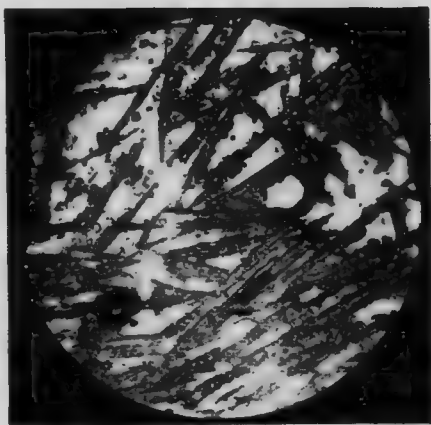


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WILLIAMS.

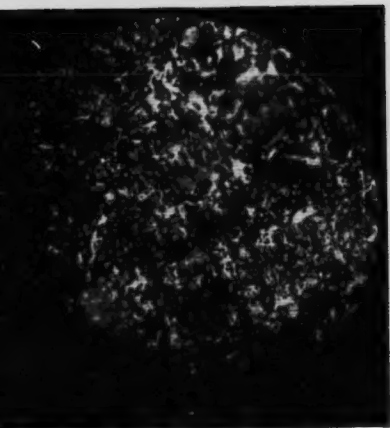


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